CONCRETE FORMED SURFACE ISSUES

minnesota concrete council
Dedicated to Cast-in-Place Concrete

1. Introduction
2. Code Specifications & References
3. Team Involvement
4. Common Issues & Mix Modifications
5. Evaluation & Repair

1

Introduction

Why are we all here?

Introduction

Now, more than ever, the as-cast concrete surface is the final surface.

- The primary goal of the construction team is to produce as-cast concrete surfaces that meet project specifications and expectations.
- Although various descriptions, interpretations, and methods exist to achieve an as-cast concrete surface, no unified definitions of different concrete surfaces exist.

The goal of this presentation is:

- To help solve the lack of uniformity in the appearance criteria of concrete surfaces
- To provide definitions for the various levels of formed concrete surfaces
- To give objective evaluation
- To give guidance on the production of "pore free" surfaces

2

Code Specifications & References

Current Documents

ACI 117 - Specifications for Tolerances for Concrete Construction

- tolerances – four categories for form offsets

A

A

A

None of these references provide a uniform appearance criteria!

ACI 347 – Guide to Formwork for Concrete

- describes four categories of formed concrete – (ACI 117)

ACI 301 -10 Specifications

ACI 301 currently specifies three categories of surface finish. These categories only consider:

- Voids
- Projections
- Tie Holes
- Tolerances
- Mockups

5.3.3.3 *As-cast finishes*—Use form-facing materials meeting the requirements of 2.2.1.1. Unless otherwise specified, produce as-cast formed finishes to comply with 5.3.3.3(a), 5.3.3(b), or 5.3.3.3(c).

5.3.3.3(a) *Surface finish-1.0 (SF-1.0):*
(a) No formwork facing material is specified
(b) Patch voids larger than 1-1/2 in. wide or 1/2 in. deep
(c) Remove projections larger than 1 in.
(d) Tie holes need not be patched
(e) Surface tolerance Class D as specified in ACI 117
(f) Mockup not required

5.3.3.3(b) *Surface finish-2.0 (SF-2.0):*
(a) Patch voids larger than 3/4 in. wide or 1/2 in. deep
(b) Remove projections larger than 1/4 in.
(c) Patch tie holes
(d) Surface tolerance Class B as specified in ACI 117
(e) Unless otherwise specified, provide mockup of concrete surface appearance and texture

5.3.3.3(c) *Surface finish-3.0 (SF-3.0):*
(a) Patch voids larger than 3/4 in. wide or 1/2 in. deep
(b) Remove projections larger than 1/8 in.
(c) Patch tie holes
(d) Surface tolerance Class A as specified in ACI 117
(e) Provide mockup of concrete surface appearance and texture

ACI 117-10 Tolerances

- The contents of ACI 301 Specification and 347 Formwork are based on the form offsets as described in ACI 117

4.8.3 *Formed surface irregularities (gradual or abrupt)*

Abrupt irregularities shall be measured within 1 in. of the irregularity. Gradual surface irregularities shall be measured by determining the gap between concrete and near surface of a 5 ft straightedge, measured between contact points.

Class A Surface..... +1/8 in.

Class B Surface..... +1/4 in.

Class C Surface..... +1/2 in.

Class D Surface..... +1 in.

SAME AS ACI 347 FORMED CONCRETE

New Document - ACI 347.3R

ACI 347.3R-13

Guide to Formed Concrete Surfaces

Reported by ACI Committee 347

- Chapter 1 – Introduction
- Chapter 2 – Definitions
- Chapter 3 – Surface Descriptions
- Chapter 4 – Layout & Design
- Chapter 5 – Specifications
- Chapter 6 – Construction
- Chapter 7 – Evaluation
- Chapter 8 – References

Formed Concrete Surface Descriptions

- Four concrete surface categories (CSC's) are defined
  - CSC 1 has the lowest classification and
  - CSC 4 has the highest level for a finished concrete surface
- Concrete surface levels can be specified for individual parts or the entire structure to reflect the owners needs and budget
- Examples include

Basement walls	CSC 1
Mechanical rooms	CSC 2
Commercial building exteriors	CSC 3 or CSC 4
High end exteriors, monuments	CSC 4

Example - Owner wanted the entire structure to be CSC 4

ACI 347.3R Table 3.1.a

Table 3.1a—Description of formed concrete surface categories (CSC)

Formed concrete surface category[1]			Description	CSC requirements[1,3]					Additional requirements				Relative costs
				Texture	Surface void ratio[2]		Color uniformity[2]		Surface irregularities	Construction and facing joint	Mockup[4]	Form-facing category[5]	
					a	na	a	na					
Concrete surface finish with	Basic requirements	CSC1	Concrete surfaces in areas with low visibility or of limited importance with regard to formed concrete surface requirements, used or covered with subsequent finish materials.	T1	SVR1	SVR1	CU1	CU1	SI1	CJ1	Optional	FC1	Low
	Normal requirements	CSC2	Concrete surfaces where visual appearance is of moderate importance.	T2	SVR2	SVR1	CU1	CU1	SI2	CJ2	Optional	FC1	Average
	Special requirements	CSC3	Concrete surfaces that are in public view or where appearance is important, such as exterior or interior exposed building elements.	T3	SVR3	SVR2	CU2	CU2	SI3	CJ3	Highly recommended	FC2	High
		CSC4	Concrete surfaces where the exposed concrete is a prominent feature of the completed structure or visual appearance is important.	T4	SVR4	SVR3	CU2	CU3	SI4	CJ4	Should be required	FC3	Very high

ACI 347.3R Table 3.1.b

TEXTURE

Table 3.1b—Description of visible effects on as-cast formed surface

Criterion	Classification	Characteristics
Texture, panel-joint[7]	T1 (Table 4.6.4)	- Acceptable gaps in adjacent formwork components ≤ 3/4 in. (19 mm) (6.1 h). - Acceptable depth of mortar loss ≤ 1/2 in. (13 mm). - Acceptable surface offsets of panel joints up to 1 in. (25 mm). (ACI 117-10, Section 4.8.3, Class D). - Allowable projections 1 in. (25 mm) from adjacent surface. (ACI 301-10, Section 5.3.3.3.a). - Form-facing material examples: Rough sawn lumber, CDX plywood, and particle board. - Imprints of modular panel frames are acceptable.
	T2 (Table 4.6.4)	- Acceptable gaps in adjacent formwork components ≤ 1/2 in. (13 mm) (6.1 j). - Acceptable depth of mortar loss ≤ 3/8 in. (10 mm). - Acceptable surface offsets of panel joints up to 1/2 in. (13 mm) (ACI 117-10, Section 4.8.3, Class C). - Allowable projections 1/2 in. (13 mm) from adjacent surface. - Form-facing material examples: Class BBOES plywood, MDO plywood. - Imprints of modular panel frames are acceptable.
	T3 (Table 4.6.4)	- Acceptable gaps in adjacent formwork components ≤ 1/4 in. (6 mm) (6.1 j). - Acceptable depth of mortar loss ≤ 1/4 in. (6 mm). - Acceptable surface offsets of panel joints up to 1/4 in. (6 mm) (ACI 117-10, Section 4.8.3, Class B). - Allowable projections 1/4 in. (6 mm) from adjacent surface (ACI 301-10, Section 5.3.3.3.b). - Form-facing material examples: HDO plywood, phenolic surface film, plastic, or steel. - Imprints of modular panel frames are acceptable.
	T4 (Table 4.6.4)	- Formwork should be grout tight. Avoid grout/mortar leakage and correct where occurs. - Permissible surface offsets of panel joints up to 1/8 in. (3 mm) (ACI 117-10, Section 4.8.3, Class A). - Form-facing material examples: HDO plywood, PSF plywood, full plastic, steel, and fiberglass. -Imprints of modular panel frames are unacceptable unless demonstrated and approved in the mockup.

ACI 347.3R Table 3.1.b

COLOR UNIFORMITY

Color uniformity[2]	CU1	- Light and dark color variations are acceptable. - Color variations between adjacent placements and layer lines are acceptable. - Rust and dirt stains are acceptable.
	CU2	- Gradual light and dark discolorations are acceptable. - Color consistency between adjacent placements and layer lines should be mostly uniform.[1] - Concrete source materials and form-facing material should be of consistent type, grade, and source to avoid causing deviations in appearance. - Rust and dirt stains are unacceptable.
	CU3	- Discolorations caused by concrete source material of different type and origin; different types or treatments of facing materials; or inconsistent treatment of concrete surfaces are unacceptable.[8] - Rust stains, dirt stains and visible pouring layers are unacceptable.

ACI 347.3R Table 3.1.b

SURFACE VOID RATIO

Table 3.1d—Concrete surface void ratio (SVR) on as-cast formed surfaces

Surface void ratio	SVR1	SVR2	SVR3	SVR4
Void area of pores of surface[a] occurring within a 24 in. x 24 in. square (610 x 610 mm)[2]	6.9 in.^{2} (4452 mm^2); D_{max} = 3/4 in. (19 mm)	5.8 in.^{2} (3742 mm^2); D_{max} = 5/8 in. (16 mm)	3.5 in.^{2} (2258 mm^2); D_{max} = 3/8 in. (9.5 mm)	1.7 in.^{2} (1095 mm^2); D_{max} = 1/4 in. (6 mm)
Suggested concrete placement practices to yield desired results	- Void area not to exceed 1.2 percent of the test area. - Standard formwork and placement practices should yield these results without any special effort. - This surface void ratio category limitation should not apply to permanently concealed concrete surfaces.	- Void area not to exceed 1 percent of the test area. - Release agent should be compatible with the form-facing material. - Formwork should be cleaned before the application of release agent. - Apply release agent thinly and uniformly. - A mockup might be beneficial.	- Void area not to exceed 0.6 percent of the test area. In addition to the efforts described for the SVR2 category: - Adequate vibration should be provided especially at features, openings, and embeds. - Concrete mixture consistency is important in achieving reproducible results. - Use revibration method at top lift. - Mockups are recommended.	- Void area not to exceed 0.3 percent of the test area. - In addition to the efforts described for the SVR2 and SVR3 categories: - Concrete design and formwork should eliminate surfaces that inhibit the upward movement of entrapped air. - Placement rate should consider vertical ascent rate of entrapped air during consolidation. - Use methods of deposition that minimize agitation at the surface that introduces entrapped air. - Mockups are required.

ACI 347.3R Table 3.1.d

SURFACE IRREGULARITIES

Surface irregularities[2]	SI1	- ACI 117-10, Section 4.8.3, Class D-Surface. - Maximum gradual deviation over a distance of 5 ft (152 cm), or abrupt deviation is 1 in. (25 mm). - Limit deflection of formwork structure to $L/240$. - ACI 117-10, Section 4.8.2 does not apply.
	SI2	- ACI 117-10, Section 4.8.3, Class C-Surface. - Maximum gradual deviation over a distance of 5 ft (152 cm), or abrupt deviation is 1/2 in. (13 mm). - Limit deflection of formwork structure to $L/360$. - ACI 117-10, Section 4.8.2 does not apply.
	SI3	- ACI 117-10, Section 4.8.3, Class B-Surface. - Maximum gradual deviation over a distance of 5 ft (152 cm), or abrupt deviation is 1/4 in. (6 mm). - Limit deflection of formwork structure to $L/360$. - ACI 117-10, Section 4.8.2 does not apply.
	SI4	- ACI 117-10, Section 4.8.3, Class A-Surface. - Maximum gradual deviation over a distance of 5 ft. (152 cm), or abrupt deviation is 1/8 in. (3 mm). - Limit deflection of formwork structure to $L/400$. - ACI 117-10, Section 4.8.2 does apply.
Construction and facing joints[4]	CJ1	- Acceptable offset of surfaces between two adjacent placements ≤ 1 in. (25 mm).
	CJ2	- Acceptable offset of surfaces between two adjacent placements ≤ 1/2 in. (13 mm). - The use of chamfer strips or similar reveals are recommended at construction joints.
	CJ3	- Acceptable offset of surfaces between two adjacent placements ≤ 1/4 in. (6 mm). - The use of chamfer strips or similar reveals are recommended at construction joints. - Construction joint locations should be coordinated with architectural design.
	CJ4	- Acceptable offset of surfaces between two adjacent placements ≤ 1/8 in. (3 mm). Offsets less than 1/8 in. (3 mm) should be specified in design documents. - The use of chamfer strips or similar reveals are recommended at construction joints. - Construction joint locations should be coordinated with architectural design and approved by architect or engineer. - The mockup should contain all features representative to the finished product.

ACI 347.3R Table 3.1.c

FORM FACING

Table 3.1c—Form-facing categories

Criterion	Form-facing category		
	FC1	FC2	FC3
Holes, greater than 3/16 in. (5 mm)	Plug or disk covers are acceptable	Acceptable if patched sanded and sealed or ground to match adjacent form surface	Visible filling is unacceptable
Holes, 3/16 in. (5 mm) or less	Acceptable	Acceptable without patching, provided form surface is not damaged or torn around hole(s)	Acceptable if patched, sanded, and sealed or grounded to match adjacent form surface
Vibrator burns	Acceptable	Unacceptable	Unacceptable
Scratches/dents	Acceptable	Acceptable if patched, sanded, and sealed or grounded to match adjacent form surface	Unacceptable unless otherwise approved
Concrete remnants[5]	Acceptable	Unacceptable	Unacceptable
Cement residue[1]	Acceptable	Acceptable	Should not affect finished concrete surface
Swelling of facing at fastener or tie holes	Acceptable	Unacceptable	Unacceptable
Patching[1]	Acceptable	Acceptable	Should not affect finished concrete surface

Summary

- Description of visible effects on as cast formed concrete
  - Texture T1-T4
  - Surface Void Ratio SVR1-SVR4
  - Color Uniformity CU1-CU3
  - Surface Irregularities SI1-SI4
  - Construction Joints CJ1-CJ4
  - Form Facing FC1-FC3

The failure of one agreed criterion in this guide should not result in rejection if the overall image of the structure is not disturbed.

3

Team Involvement

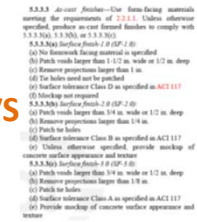
The goal is now set by the owner… "I want to have a high quality surface…"

So…….how do we build it?

Architect

- What do they really want of that concrete element
  - **Aesthetics**
- Use of pictures and site visits vs. ACI code references and pour specifications

VS



5.3.3.3 *As-cast finishes*—Use form-facing materials meeting the requirements of 2.2.1.1. Unless otherwise specified, produce as-cast formed finishes to comply with 5.3.3.3(a), 5.3.3(b), or 5.3.3.3(c).

5.3.3.3(a) *Surface finish-1.0 (SF-1.0)*:
(a) No formwork facing material is specified
(b) Patch voids larger than 1-1/2 in. wide or 1/2 in. deep
(c) Remove projections larger than 1 in.
(d) Tie holes need not be patched
(e) Surface tolerance Class D as specified in ACI 117
(f) Mockup not required

5.3.3.3(b) *Surface finish-2.0 (SF-2.0)*:
(a) Patch voids larger than 3/4 in. wide or 1/2 in. deep
(b) Remove projections larger than 1/4 in.
(c) Patch tie holes
(d) Surface tolerance Class B as specified in ACI 117
(e) Unless otherwise specified, provide mockup of concrete surface appearance and texture

5.3.3.3(c) *Surface finish-3.0 (SF-3.0)*:
(a) Patch voids larger than 3/4 in. wide or 1/2 in. deep
(b) Remove projections larger than 1/8 in.
(c) Patch tie holes
(d) Surface tolerance Class A as specified in ACI 117
(e) Provide mockup of concrete surface appearance and texture

Engineer

- What do they really want out of that concrete element
  - **Strength, consistency, minimal cracking**
- How can engineers work better with the contractor
  - Performance vs Prescriptive (ACI and spec)
  - Involve the Concrete Supplier and Contractor

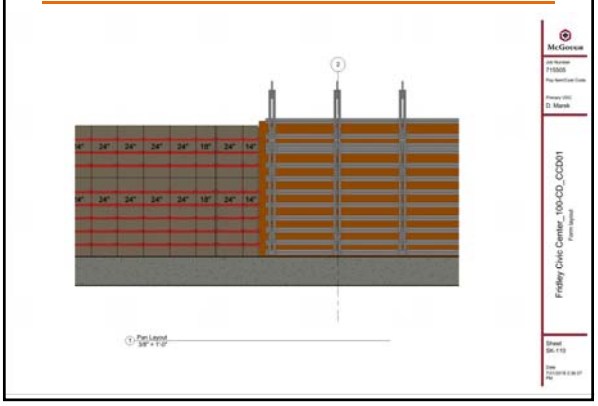
Formwork and Construction Supplier

- What do they need to know to help achieve the correct concrete look?
- Good vs bad formwork results
  - Form facing material
  - Form liners or skim panels
  - Pour rates match contractor approach
  - Understanding the construction sequence/process

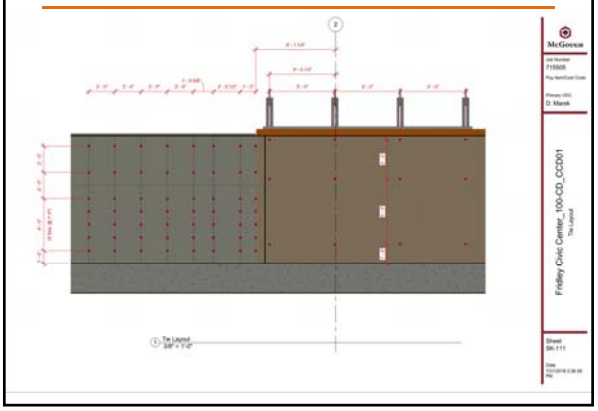
Contractor

- Design team expectations
- Formwork considerations
  - Type
  - Panelized or job built
  - Form facing material
  - Release agents
  - Joint locations
  - Rebar congestion (Pouring it)
  - Form tie locations
  - Reveals
  - Concrete pressure & pouring time considerations
  - Number and size of block outs
- Construction considerations
  - Location and Region
  - Pump or bucket
  - Weather (Rain, Sun, Wind)
  - Mockup results
- Consolidation methods
  - Internal vs. external vibration

Contractor – Joint Coordination

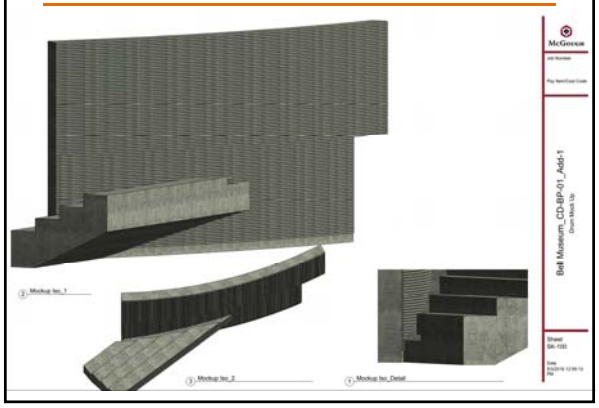


Contractor – Joint Coordination

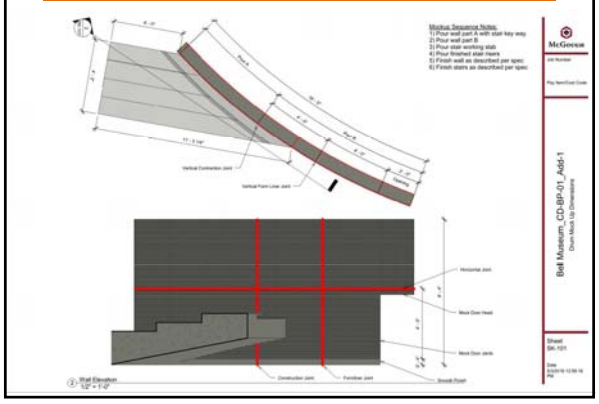


Contractor – Joint Coordination

Contractor - Mockups



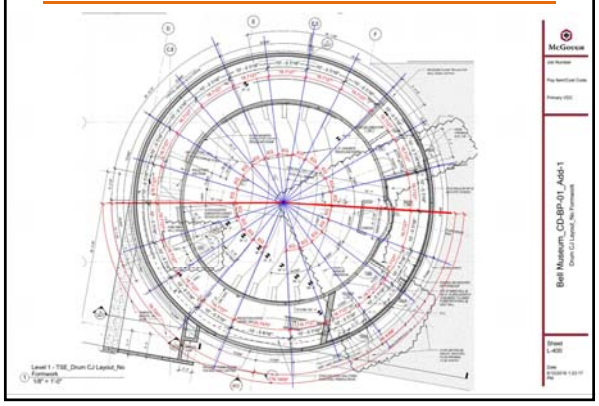
Contractor - Mockups



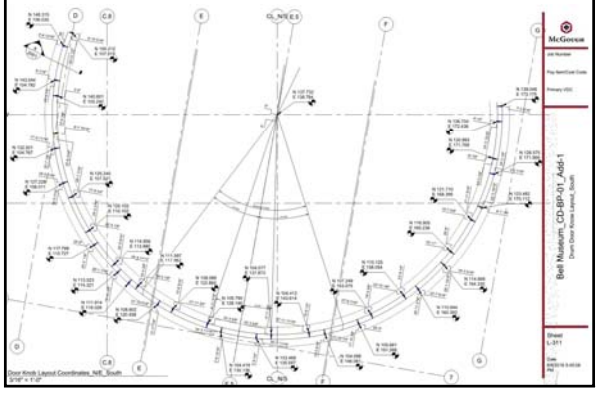
Contractor - Mockups

- Include ALL variations
  - Architectural
  - Structural
  - Contractor
- Set real expectations
- DETAILS MATTER!

Contractor - Mockups



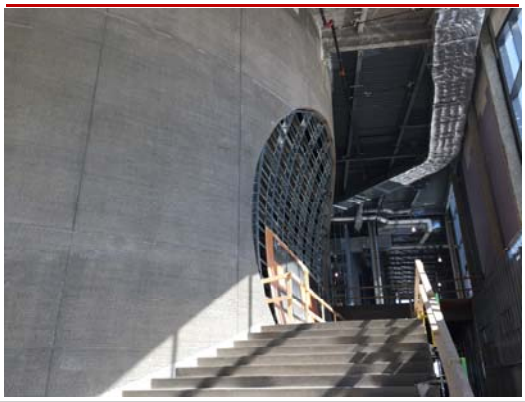
Contractor - Mockups



Contractor - Mockups

Contractor - Mockups

Contractor - Mockups



Contractor - Constructability

Contractor - Constructability

Contractor - Constructability

Contractor - Constructability

Ready Mix Supplier

- What do they need to know to help achieve the correct concrete look?
  - Strength at a duration
  - Placement method
  - Weather and admixtures
  - Common issues & mix design modifications
  - Who is pouring and what team?

Team Work = Success!

4

Common Issues & Mix Modifications

MIX DESIGNATION	MIX #	R2007
DESIGN COMPRESSIVE STRENGTH - 28 DAYS		4000 PSI
PLACEMENT LOCATION		
COARSE AGGREGATE SIZE (MAX)		3/4" - #4
SLUMP		4 INCH
AIR CONTENT		
DESIGN MIX		
1 - CEMENT - LBS.		410
2 - FLYASH - LBS.		100
5 - WATER REDUCER - OZ./CWT		3
3 - FINE AGGREGATE - LBS.		1468
4 - COARSE AGGREGATE (3/4" - #4)		1849
WATER - LBS.		255
WATER CEMENT RATIO		0.50
SLUMP		4 INCH
AIR CONTENT (CALCULATED)		2.50%

MIX DESIGNATION	MIX #	8737
DESIGN COMPRESSIVE STRENGTH - 28 DAYS		4000 PSI
PLACEMENT LOCATION		
COARSE AGGREGATE SIZE (MAX)		3/4" - #4
SLUMP		6 - 8 INCH
AIR CONTENT		
DESIGN MIX		
1 - CEMENT - LBS.		515
2 - FLYASH - LBS.		125
5 - SUPERPLASTICIZER - OZ.		29
6 - VISCOSITY MODIFIER - OZ.		19
3 - FINE AGGREGATE - LBS.		1250
4 - COARSE AGGREGATE (3/4" - #4)		1580
4 - COARSE AGGREGATE (3/8" - #8)		320
WATER - LBS.		269
WATER CEMENT RATIO		0.42
SLUMP		6 - 8 INCH
AIR CONTENT (CALCULATED)		2.50%

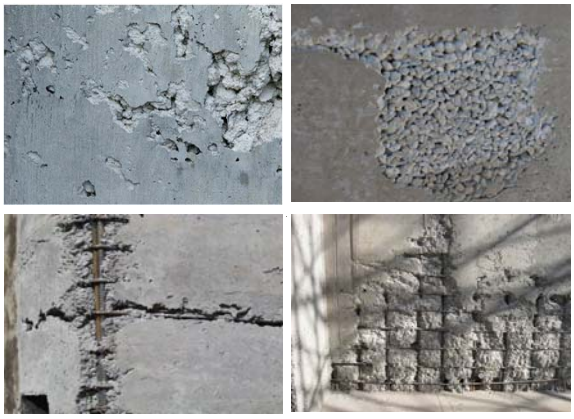
MIX DESIGNATION	MIX #	8819
DESIGN COMPRESSIVE STRENGTH - 28 DAYS		6000 PSI
PLACEMENT LOCATION		SCC
COARSE AGGREGATE SIZE (MAX)		3/4" - #4
SPREAD		26 - 30 INCH
VISUAL STABILITY INDEX (VSI)		1 OR LESS
STATIC SEGREGATION (%)		0-10
DESIGN MIX		
1 - CEMENT - LBS.		680
2 - FLYASH - LBS.		120
5 - SUPERPLASTICIZER - OZ.		48
6 - VISCOSITY MODIFIER - OZ.		40
3 - FINE AGGREGATE - LBS.		1290
3 - COARSE AGGREGATE (3/4" - #4)		890
4 - COARSE AGGREGATE (3/8" - #8)		770
WATER - LBS.		288
WATER CEMENT RATIO		0.36
SLUMP		26 - 30 INCH
AIR CONTENT (CALCULATED)		2.00%

Common Issues

1. Color Uniformity
2. Honeycombing
3. Bug Holes
4. Sand streaks
5. Pour Lines

Color Uniformity

Probable Causes	Solutions
Mix constituent changes →	Keep mix consistent
Formwork type/residue →	Fly ash changes
Form release →	Proper type & application rate
Efflorescence →	Stop the movement of moisture (very important for integral color)



Honeycombing

Probable Causes	Solutions
No/improper vibration	
Low paste content →	Increase paste content
Increased slump →	Use of hydration stabilizers & slump retainers
Fast concrete set	
Reinforcement issues →	Use well graded aggregates smaller top size aggregate SCC
Paste bleed? →	

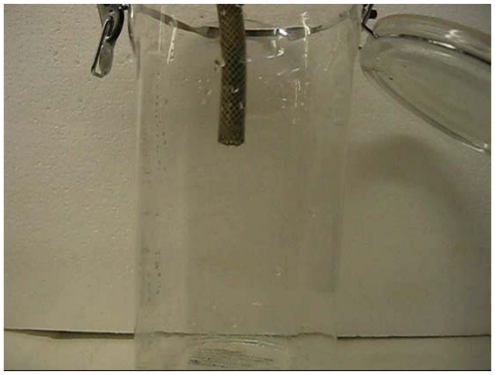
MIX DESIGNATION	MIX #	8737
DESIGN COMPRESSIVE STRENGTH - 28 DAYS		4000 PSI
PLACEMENT LOCATION		
COARSE AGGREGATE SIZE (MAX)		3/4" - #4
SLUMP		6 - 8 INCH
AIR CONTENT		
DESIGN MIX		
1 - CEMENT - LBS.		515
2 - FLYASH - LBS.		125
5 - SUPERPLASTICIZER - OZ.		29
6 - VISCOSITY MODIFIER - OZ.		19
3 - FINE AGGREGATE - LBS.		1250
4 - COARSE AGGREGATE (3/4" - #4)		1580
4 - COARSE AGGREGATE (3/8" - #8)		320
WATER - LBS.		269
WATER CEMENT RATIO		0.42
SLUMP		6 - 8 INCH
AIR CONTENT (CALCULATED)		2.50%

Paste Bleed

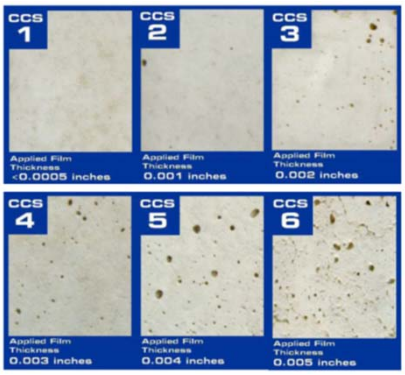
Bug Holes

Probable Causes	Solutions
• Vibration →	• Proper vibrator selection
• Entrained/entrapped air →	• Does it need air?/defoamer
◦ Pumping	◦ Keep hopper full
◦ Drop into form	◦ Pump from bottom
	◦ tremie hose in concrete
	◦ Air needs escape route
• Form release →	• Proper type and rate!!!

Bug Holes



Bug Holes



Pour lines

Probable Causes	Solutions
Mix setting too rapidly	Use hydration stabilizers
Slow pour rate	Use slump retainers
Too little vibration	Proper vibrator selection and use
	SCC? (formwork pressure?)

5

Evaluation & Repair

Evaluation

Establish a concrete surface team for CSC3 & CSC 4 surfaces

- Owner
- Licensed design professional
- General and/or concrete contractor
- Formwork supplier
- Concrete producer

Tasks

- Clarify surface appearance requirements
- Clarify forming and pouring requirements
- Identify mockup requirement

Evaluation

The **OVERALL IMPRESSION** of the concrete surface appearance is the basic acceptance criteria.

- Appropriate viewing distance of minimum 20 feet
- Distance that allows the entire building to be viewed
- Avoid acute angles of sun during evaluation

Mockup should be used in the evaluation process as well as for eventual repair procedures

Thank You!

McGOUGH

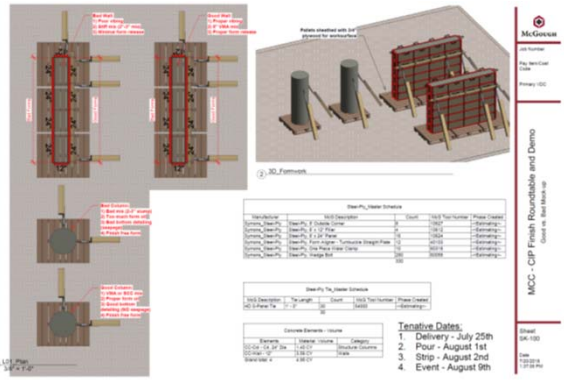
WACKER NEUSON

DAYTON SUPERIOR

SYMONS By Dayton Superior

LABORERS TRAINING CENTER LIUNA LTC Training & Education Fund MN & ND

SUBSURFACE CONSTRUCTORS INCORPORATED

AVR Celebrating 50 Years of Quality Concrete www.avrconcrete.com

Demonstration Layout